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GENERAL NOTES

The Interior of a Star[1]; *A Review.*—Professor A. S. Eddington of Cambridge, England, has derived some singularly important conclusions as the result of a theoretical study of the interiors of stars. Altho the problem of the conditions within a star appears very difficult, it is, nevertheless, theoretically simpler than the study of the interior of the Earth. The diffuse giant stars are very favorably adapted to this problem. On account of their extremely low densities they may be considered as large, intensely heated spheres of gas, acting in accordance with the laws of the kinetic theory of gases. Since the visible exteriors of these stars are vastly hotter than any terrestrial heat source, it must follow that near their centers the temperature must rise to some millions of degrees Centigrade. It is well to consider whether such a temperature, which is so far outside our experience, can be taken literally. In a mass of helium at 10,000° the ultimate particles move at the average rate of about 7.3 kilometers per second; at 1,000,000° the rate is 73 kilometers per second. Thus a hundred-fold increase in temperature means only a ten-fold increase of molecular speed. We never hesitate to accept the first temperature with its corresponding molecular speed, and there seems to be no reason why we should not accept the second with its corresponding molecular speed, since such speeds are not unknown in the laboratory. (It has been found, for instance, that alpha particles move with speeds approaching the speed of light.)

The existence of a high temperature in the interiors of stars should encourage investigation because it simplifies the problem. Under such conditions the radiant energy is not light in the ordinary sense; it becomes X-rays for which the absorption approaches more uniform laws. Further, at high temperatures the complex structures of the atoms are broken down into their constituent parts and thus the entire mass becomes homogeneous in composition.

Professor Eddington has calculated the temperature conditions within a typical star of mass 1.5 times that of the Sun, and density 0.002. At the center, where the temperature, pressure, and density are greatest, the temperature is 4,700,000°; the density is about one-ninth that of water and the pressure is 21,000,000 atmospheres. Half way from the center to the surface the temperature is

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[1] A. S. Eddington, The Interior of a Star, *Scientia*, Vol. XXIII, No. LXIX, 1, 1918; also *Astrophysical Journal*, November, 1918.

1,300,000°, four-fifths of the way it is 330,000°. Altho the decline in temperature as the surface is approached appears rapid, the temperature gradient is only 1.5° per kilometer—much less than that of the Earth's atmosphere. The effective temperature of this star is 6,500°; *i. e.* if the star were a black body at that temperature it would radiate as much heat as the actual star does. From Professor Eddington's theory it appears that for giant stars of equal masses the effective temperature is proportional to the sixth root of the density.

There is a close correspondence between spectral type and effective temperature. The class M stars have an effective temperature of about 3,000°. Stars with spectra like the Sun's (class G) have an effective temperature of 6,000°; for the white Sirian stars (class A) it is 11,000°; and for the hottest of all, the helium stars (class B), it may be estimated at 15,000°.

By taking account of the probable nature of the deviations from the laws of a perfect gas, Professor Eddington has extended his studies to the denser stars. The results of course are much more uncertain. As the star passes thru the various steps of the ascending temperature series of stellar evolution (the giant stage) the effective temperature rises as the surface contracts. It is of interest to inquire whether the net result is a loss or gain in brightness, since the decreasing area and the increasing radiation per unit area tend in opposite directions. The temperature-density law, stated in a previous paragraph, supplies the answer. The two tendencies just balance each other and therefore the total luminosity remains constant. The star reaches its greatest effective temperature when its density is 0.2 to 0.4. After that it enters the descending temperature series (dwarf stage), and from then on there is a rapid decline of temperature as the density slowly increases. The luminosity also falls off rapidly, since both surface and surface brightness are decreasing. The maximum temperature and luminosity are proportional to the star's mass. Differences in absolute magnitude of stars in a similar stage of stellar evolution may therefore be attributed to differences in mass. It may be noted, however, that the range of observed mass differences is very small. A ratio of 1:3 would include nearly five-sixths of all the known star masses. A body with mass less than one-seventh the Sun's mass would never attain 3,000°, which is the lowest temperature admissible if it is to shine as a star. As yet no star with such a small mass has been found. The Sun may have reached a temperature of 9,000°, a little lower than that of *Sirius* at present; it is now 6,000°. In order to attain the helium stage (class B), which is the hottest of all, a star's mass must be at least 2.5 times that of the Sun. It is significant that observations of class B stars have shown them to be on the average three times as massive as the average star.

Heretofore astrophysicists have not considered radiation pressure as a factor in theories of stellar equilibrium and evolution. Professor Eddington shows that for stars of sufficient mass, the pressure of internal radiation may nearly neutralize the force of gravitation. He has computed the ratio of radiation-pressure to gravitation for stars of various masses. The values are given in the following table, where *M* is the mass in terms of the Sun and *R* is the ratio of radiation-pressure to gravitation:

M	*R*
0.5	0.036
1.0	.106
1.5	.174
3.0	.320
4.5	.409

There is a significance in the rapid increase of radiation-pressure with increasing mass, which may appear clearer from another standpoint. Taking a series of globes of perfect gas, the first being a mere bubble containing 10 grams, the second 10^2 grams, the third 10^3 grams, and so on, Professor Eddington calculated the ratio of radiation-pressure to gravitation for each of these "stars." For the first thirty-three spheres—those with masses from 10 to 10^{33} grams—radiation-pressure is less than one-tenth of gravitation. From the thirty-fifth sphere onward the ratio is more than eight-tenths (it is always less than unity). We see, therefore, that thruout the first group radiation-pressure is only of trivial importance; but that in the second group it must entirely change conditions, since it neutralizes the greater part of gravitation. The transition between the two conditions of the series is represented by the single sphere of mass 10^{34} grams. The interesting point about this mass of 10^{34} grams is that it represents quite closely the usual masses of stars, being, in fact, five times that of the Sun. The coincidence is striking. The material of the universe has been aggregated into stellar bodies which are remarkably uniform in mass. By a simple argument from the properties of matter, involving only constants determined in the laboratory, Professor Eddington has singled out a critical mass—one at which a vital change of condition takes place—and shows that this mass is very near the average stellar mass. A star would become unstable if its mass were much larger than this. The radiation-pressure would be so great that gravitation could not hold it together. A body with a mass much less than the critical mass could never attain incandescence. The range for stellar masses is therefore definitely limited and we are led to believe with Professor Eddington that "radiation-pressure is indeed the prime agent which has fashioned chaos into stars."

Hugo Benioff.

The Evolution of the Binary Systems[1]; *A Review.*—In the December *Monthly Notices* there appears a discussion on "The Evolution of Binary Systems," by J. H. Jeans. In it are discussed different hypotheses as to the evolutions of binary systems with special reference to their periods and eccentricities. The following hypotheses are considered:

(A)[2] The periods and dimensions of orbits of binary stars are at present undergoing changes of the same nature as those which in the past have brought them to their present state of development.

(B) "The periods and dimensions of orbits of binary stars are permanently fixed, and have retained approximately their present values thru the whole of the star's life."

(C) "The periods and dimensions of orbits of binary stars, altho now definitely fixed, have been determined as the result of interactions with other stars in some past epoch in which these interactions were not negligible."

Considering (A) the author points out the fact that at present the interactions of adjacent stars are entirely inadequate to produce appreciable changes in the periods and dimensions of binary stars. We know of no other external forces which might be effective. This leaves only internal forces to be considered. It is shown from the principle of the constancy of the moment of momentum of an undisturbed system that great changes could not occur in the dimensions of the orbits except thru the agency of external forces. In particular any increase in the moment of momentum due to orbital revolution must be at the expense of the moment of momentum due to axial rotation. Now such an increase in the moment of momentum due to orbital revolution must occur if the semi-major axis increases. It is readily shown that the axial rotation does not provide a sufficiently large store of moment of momentum to account for any great increase in the semi-major axis. These considerations render (A) untenable.

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[1] J. H. Jeans, The Evolution of the Binary Systems, ***Mon. Not. R. A. S.*** **79**, 100, 1918.

[2] This hypothesis is not stated explicitly by the author, but it is discussed.

With regard to (B) the author considers that Russell's investigation[3], "On the Origin of Binary Stars," provides a strong proof that binary and triple systems have originated by fission. Such systems of long period as *a Centauri*, however, if formed by fission must originally have had a much smaller orbit, because if the object had remained unchanged, it would require that the density of the body at fission had been so low as to make fission practically impossible. This eliminates hypothesis (B).

There only remains (C). Encounters with other stars are considered as a means of altering the elements of a binary orbit. The author shows that after a sufficient number of encounters with other stars the eccentricity will become about 0.64 regardless of what it was originally. He states that the mean eccentricity of known binary orbits is slightly less than 0.6, so that the agreement with theory is satisfactory when we consider that we should not expect that all of the stars had reached the equilibrium conditions produced by a very large number of encounters. He states that the period will depend on the mass of the binary and on the velocity of translation of its center of gravity thru space. For a star ten times the mass of our Sun and whose velocity of translation thru space is 8 kms. a second, the period would be eighty years. This is of the right order of magnitude.

As the stellar system is now constituted encounters are too rare to have any such effects in conceivable time. If, however, the stellar system was once a nebula from which the stars have condensed, it must have been much smaller than at present to account for the large masses of the Sun and stars.

Such being the case, encounters must have been much more frequent and the orbits of binary stars thus brought to their present state. Since then the stellar system must have undergone an expansion and may even now be expanding. The observed excess radial velocities of stars of the different spectral types are considered by the author to be possibly a result of this expansion. If the B-type stars were formed after the stellar system had expanded somewhat, they must have suffered less from encounters than the older stars. The short periods of those among them that are binaries, together with the fact that they show a tendency to group themselves in clusters of stars having a common motion lends support to this view.

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[3] H. N. Russell, On the Origin of Binary Stars, *Ap. Jour.*, **31**, 185, 1910.

C. D. Shane.

Comet 1918a (*Reid*).—A brief note in the December, 1918, number of these Publications called attention to the discovery of an unexpected comet on June 11, 1918, by Mr. William Reid of South Africa. At that time, and until very recently, the original cable announcement of the discovery was the only information which had been received. The elapsing of many months without supplementary knowledge was due exclusively, it seems, to the difficulties of communication arising from war conditions. A letter written by Mr. Reid and addressed to the chairman of the Comet Medal Committee of this Society travelled only as far as London, whence it was returned to the sender.

Recent information from the Cape of Good Hope Observatory and from Mr. Reid establishes that the comet was kept under observation for nearly two months and that it followed closely the orbit computed by Mr. H. E. Wood of the Union of South Africa Observatory. Several satisfactory photographs were obtained at the Cape Observatory.

The comet passed perihelion about June 5, 1918, at a distance approximately 1.08 times the Earth's mean distance from the Sun, and its orbit plane made an angle of about 70° with the plane of the ecliptic.

Promptly following the receipt of the above information the Donohoe Comet Medal of the Astronomical Society of the Pacific was awarded to Mr. Reid, as announced on another page of this number of the Publications.

Mr. Reid is an enthusiastic comet seeker. He has found several comets, but the comet of last June is the only one of which he has been the earliest discoverer. His observatory is equipped with a 4-inch Alvan Clark refractor and a 6-inch Cooke refractor.

W. W. Campbell.

A Tribute to Professor E. C. Pickering.—At the seventh annual meeting of the American Association of Variable Star Observers, which was held at the Harvard College Observatory, Cambridge, Mass., on November 23, 1918, a solid gold paper-knife set with alexandrite and a star-sapphire was presented to Professor E. C. Pickering, by the Association. The reverse of the inscription reads: "This token of appreciation is tendered to him who has done so much to promote the study of variable stars; guiding the amateur with untiring helpfulness along paths of understanding into fields of usefulness and pleasure."

It is fitting that the last public tribute paid to Professor Pickering was in recognition of his encouragement of the work of others.

Correction to a Note on the Size of the Hydrogen Envelop Star—In lines 3 and 5 of page 64 of the February, 1919, number of these PUBLICATIONS, the value of the parallax of the star should read 0″.0006 instead of 0″.006, as may be seen from the simple application in the note.

W. CARL RUFUS.